



These Schematic Energy-Band Profiles are typical of a bipolar cascade laser.

Inasmuch as the tunneling current is approximately inversely proportional to the exponential of the barrier height, the introduction of quantum wells into the Esaki tunnel junction can significantly reduce the electrical resistance of the junction and thereby reduce the amounts of dopants needed. Further-

more, the numbers and shapes of the quantum wells constitute additional degrees of freedom in design that can be used to tailor carrier-transport and potential profiles to optimize laser performance.

Going beyond bipolar cascade lasers, the present innovation could also be

beneficial in some light-emitting diodes and single-stage semiconductor lasers that contain Esaki tunnel junctions. For example, quantum wells could be incorporated into vertical-cavity surface-emitting lasers, wherein Esaki tunnel junctions are used to connect n-doped mirrors to avoid the use of p-doped resistive mirrors.

*This work was done by Rui Q. Yang and Yueming Qiu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## Phytoplankton-Fluorescence-Lifetime Vertical Profiler

**A compact, battery-powered instrument measures marine chlorophyll fluorescence at depths  $\leq 300$  m.**

*Stennis Space Center, Mississippi*

A battery-operated optoelectronic instrument is designed to be lowered into the ocean to measure the intensity and lifetime of fluorescence of chlorophyll A in marine phytoplankton as a function of depth from 0 to 300 m. Fluorescence lifetimes are especially useful as robust measures of photosynthetic productivity of phytoplankton and of physical and chemical mechanisms that affect photosynthesis. The knowledge of photosynthesis in phytoplankton gained by use of this and related instruments is expected to contribute to understanding of global processes that control the time-varying fluxes of carbon and associated biogenic elements in the ocean.

The concentration of chlorophyll in the ocean presents a major detection challenge because in order to obtain accurate values of photosynthetic parameters, the intensity of light used to excite fluorescence must be kept very low so as not to disturb the photosynthetic system. Several innovations in fluorometric instrumentation were made in order to make it possible to reach the required

low detection limit. These innovations include a highly efficient optical assembly with an integrated flow-through sample interface, and a high-gain, low-noise electronic detection subsystem. The instrument also incorporates means for self-calibration during operation, and electronic hardware and software for control, acquisition and analysis of data, and communications. The electronic circuitry is highly miniaturized and designed to minimize power demand. The instrument is housed in a package that can withstand the water pressure at the maximum depth of 300 m.

A light-emitting diode excites fluorescence in the sample flow cell, which is placed at one focal point of an ellipsoidal reflector. A photomultiplier tube is placed at the other focal point. This optical arrangement enables highly efficient collection of fluorescence emitted over all polar directions. Fluorescence lifetime is measured indirectly, by use of a technique based on the same principle as the one described in "Fluorometer for Analysis of Photosynthesis in Phyto-

plankton" (SSC-00110), *NASA Tech Briefs*, Vol. 24, No. 1 (November 2000), page 79. The excitation is modulated at a frequency of 70 MHz, and the phase shift between the excitation light and the emitted fluorescence is measured by a detection method in which the 70-MHz signal is down-converted to a 400-Hz signal. The fluorescence lifetime can be computed from the known relationship among the fluorescence lifetime, phase shift, and modulation frequency.

In operation, the instrument measures fluorescence intensity and lifetime repeatedly, according to a schedule established during an instrument set-up process, in which the instrument is connected to a host computer. Once programmed, the instrument is disconnected from the computer and remains in a quiescent state as it is placed in the ocean. The measurement process is started by use of a magnetically actuated switch. Measurements taken by the instrument are recorded in a memory module that can hold the data from more than 28,000 measurements. The

set of data from each measurement is time-stamped and includes a pressure/depth datum. Switching the instrument off terminates the series of measurements and prepares the instrument for the next series of measurements. At the end of a series of measurements, the instrument is reconnected to the host computer and the measurement data

are uploaded from the instrument's memory module to the computer.

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